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IN SITU BACKFILL TESTING WITH A BOREHOLE DILATOMETER

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JULY 1983

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35 pp

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 83-64 (TR)

IN SITU BACKFILL TESTING WITH A BOREHOLE DILATOMETER

by

G. Swan* and G. Vaillancourt**

ABSTRACT

Borehole dilatometer tests were recently conducted at two mines with widely different backfills, one a weakly cemented rockfill, the other a well cemented hydraulic fill.

The dilatometer probe dimensions are 1 m x 115 cm diameter and it was designed for use in backfill rather than for conventional soil mechanics applications.

Calibration tests were done at regular intervals and a borehole TV camera was used to inspect the holes for integrity.

The test results, particularly for the well cemented fill, showed a strong linear dependency of volume upon pressure over the pressure range 0.6 to 2.0 MPa. Laboratory values of deformation modulus were obtained from uniaxial compression tests for comparison.

The dilatometer is a useful and cost effective tool for the investigation of in situ backfill properties up to its pressure limit of 2 MPa.

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L'ETUDE SUR PLACE DU REMBLAI AVEC UN DILATOMETRE DE TROU DE MINE

par

G. Swan* et G. Vaillancourt**

RÉSUMÉ

On a récemment effectué des essais avec un dilatomètre de trou de mine dans deux mines possédant des remblais très différents; l'une un stérile faiblement cimenté et l'autre un remblayage hydraulique bien cimenté.

Les dimensions du dilatomètre sont de 1 m x 115 cm; il est conçu pour être utilisé dans les remblais plutôt que pour des applications conventionnelles en mécanique des sols.

On a effectué des tests de calibrage à intervalles réguliers, et on s'est servi d'une caméra de télévision dans les trous de mine pour examiner l'intégrité des trous.

Les résultats des essais, particulièrement ceux avec le remblayage bien cimenté, ont indiqué une forte dépendence du volume envers la pression, au-delà du champ de pression de 0.6 à 0.2 MPa. Les valeurs de laboratoire du module de déformation furent obtenues au moyen d'essais de compression uniaxiale, à des fins de comparaison.

Le dilatomètre est un outil utile et économique pour les enquêtes sur place relatives aux propriétés des remblais jusqu'à la limite de pression de 2 MPa.

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INTRODUCTION

For over twenty years the use of borehole dilatometers in soils and foundation engineering has proved valuable for the in situ assessment of strength and deformation properties. In rock mechanics applications, dilatometer devices have measured the in situ deformation modulus of hard rock, notably through the use of the CSM Cell (1). Another less well exploited application features its use for investigating in situ backfill properties after periods of one or two years from placement.

Concerning the latter, CANMET has recently initiated a program of in situ measurements at two mine sites with widely differing backfills. At Les Mines Selbaie, Quebec, the backfill is a weakly cemented rockfill (2) placed in a blast hole stope at 150 m level with a designed free standing height of 30 m. Initial measurements, taken in a test drift at 170 m, will be repeated at a later date following the removal of an adjacent pillar.

Secondly, in a well-cemented hydraulic fill at Falconbridge's Lockerby Mine, measurements were initiated from the overcut and undercut levels next to the filled 22-143 stope, approximately 700 m below surface. Measurements continued during the blasthole mining sequence of the adjacent 22-139 stope, exposing 38 m of free standing backfill. Re-entry and repetition of measurements is planned in the overcut level following the filling of 22-139.

The following constitutes a progress report describing in detail the methods used and results obtained to date at these two sites. These data, when complete, will represent two dissimilar time-dependent case histories of in situ backfill behaviour under load. It is hoped that the possibility will then exist to better understand design requirements of backfills in general.

INSTRUMENT DESCRIPTION

The dilatometer equipment* used in the present study is conventional in comprising of a combination volumeter-manometer connected to a cylindrical borehole expansion device or probe, Fig. 1. However, the dimensions of the probe (1 m x 115 mm dia) are larger than those of a soils engineering equivalent, thereby reducing the effect of particle size upon results, particularly in cemented rockfill tests. The pressure limit of this device is approximately 2 MPa which is inadequate to achieve a 'limit' or failure condition in most consolidated fills. The usefulness or even existence of such a well-defined limit in backfills is not certain however, in contrast to soil mechanics applications (3). It is expected that the instrument's capability to measure deformation modulus will though, of itself, provide data concerning stress (failure) levels; time-dependent stiffening might reflect increasing stress levels, etc.

GENERAL PRINCIPLES

During the course of performing a dilatometer test the change in system volume, V, is systematically monitored as a function of applied pressure, P (4). Following (1), a calibration procedure is then used to separate change in borehole volume from the system or total volume change.

For the present probe, a calibration cylinder of thin-walled aluminum was used, providing a stiffness (pressure per unit volume change) M_c given by:

$$M_c = E_c/2(1 + \nu_c)\pi L r^2_{ic}[(1 + \beta_c - 2\nu_c\beta_c)/(1 - \beta_c)] \qquad \text{Eq 1}$$

where, $\beta_c = (r_{ic}/r_{oc})^2$

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* made under contract by Civil Engineering Dept., University of Alberta.

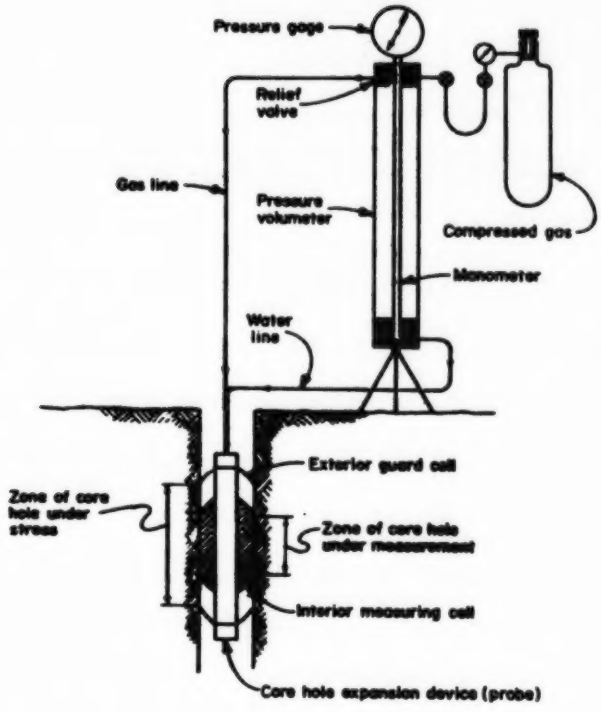

Fig. 1 - Schematic of dilatometer equipment.

and, L = effective length, measuring cell = 340 mm

r_{ic} = inside radius, calibration cylinder = 64.33 mm

r_{oc} = outside radius, calibration cylinder = 71.12 mm

E_c = elastic modulus, calibration cylinder = 69.0 GPa

v_c = Poisson's ratio, calibration cylinder = 0.33

Using these data M_c = 834.8 GPa/m^3

If , from a test with the probe dilating the cylinder, a stiffness M_m is observed, the dilatometer system stiffness only, M_s, can be calculated using:

$$M_s = (M_c\ M_m)/(M_c - M_m) \qquad \text{Eq 2}$$

Finally, from the linear portion of the dilatometer's pressure-volume characteristics measured in the backfill borehole, the experimental stiffness, M_t, can be obtained and corrected for true borehole stiffness through:

$$M_B = (M_s\ M_t)/(M_s - M_t) \qquad \text{Eq 3}$$

The backfill's deformation modulus will then be given by:

$$E_B = 2(1 + v_B)M_B\Pi Lr^2 \qquad \text{Eq 4}$$

where, v_B is the backfill's Poisson's ratio

and r is the borehole radius.

Implicit in the derivation of (4) is the assumption of linear elastic behaviour. Furthermore the geometry of the borehole should be cylindrical with a well-defined radius ($E \propto r^2$). Since none of these conditions are likely to be perfectly fulfilled in the testing of backfill, some compromise in evaluating E_B through (4) with appropriate corrections is permissible. A good averaging approach to define r experimentally is as follows:

- inflate measuring cell to some nominal pressure and read stabilized manometer head, h_o. Measure cell's perimeter, C.
- place probe in borehole and operate using standard procedures (4) to achieve

a 'seated' condition. This typically requires a measuring cell pressure of 150 kPa for a guard cell differential of 150 kPa. When (and if) the manometer stabilizes take head h_f. Calculate seating volume $V_c = (h_f - h_o)K_v$, where K_v is the volume calibration constant.

- after test, perform linear regression to (P,V) data within the linear interval of measurements, Fig. 2. Obtain slope $(1/M_t)$ and intercept, $V_o - V_s$.
- taking the volume, V_o, as the capacity directly related to the change in measuring cell diameter, C/Π to $2r$ (L remaining constant), the desired radius will be given by:

$$r = \frac{1}{2}\sqrt{\frac{4V_o}{\Pi L} + (C/\Pi)^2} \qquad \text{Eq 5}$$

Using the slope $(1/M_t)$ and knowing M_s and r, Equations 3 and 4 can be applied to calculate E_B. In the current work $\nu_B = 0.20$ will be assumed since typically Poisson's ratio for backfill varies between 0-0.40.

CALIBRATION RESULTS

During the course of a test program air may leak into the otherwise water filled measuring cylinder and connecting water lines. For this reason calibration tests are recommended at regular intervals. The precise determination of $M_m(P)$ is not required in general since typically $M_m >> M_t$ and only the linear 'elastic' range of behaviour is relevant. An experimental value for M_m based upon Lockerby Mine test calibrations, Fig. 3, and Table 1 is 89.3 GPa/m^3. The dilatometer stiffness, M_s, a constant provided the probe remains physically unchanged, is equal to 100 GPa/m^3 from Equation 2.

It is interesting to note from Table 1 that the method used to derive r experimentally is well justified by the good agreement achieved with actual values, i.e., $r \simeq r_{ic} = 64.3$ mm.

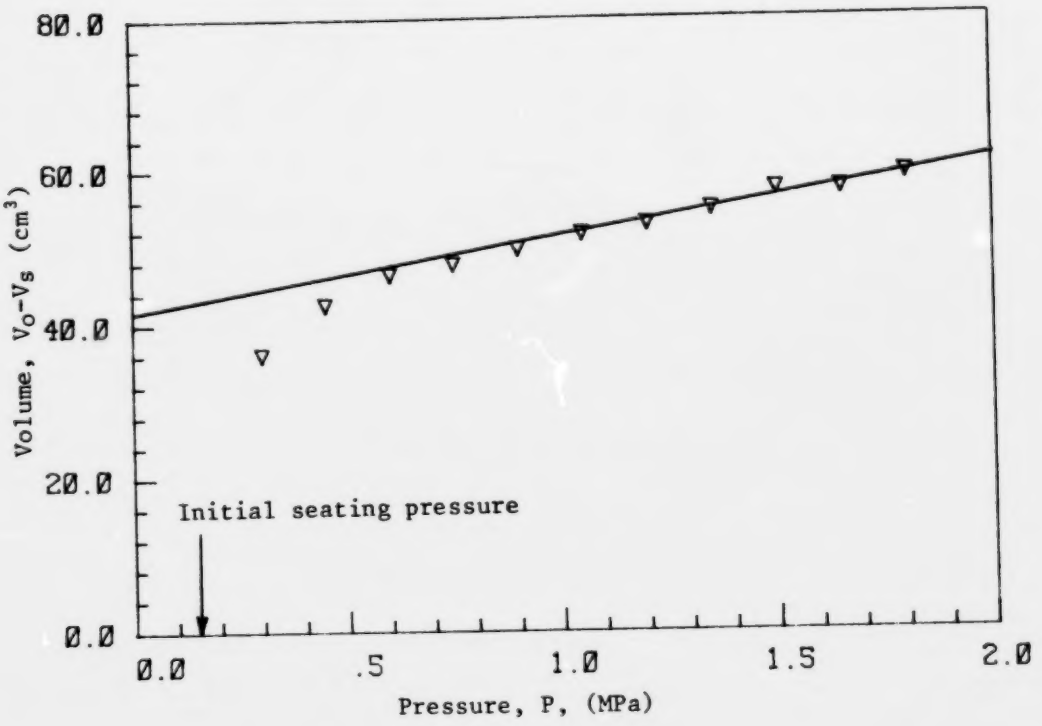

Fig. 2 - Example of a dilatometer calibration characteristic showing 'best-fitted' straight line.

Calibration Test	Symbol
1	■
2	▽
3	△
4	□
5	+

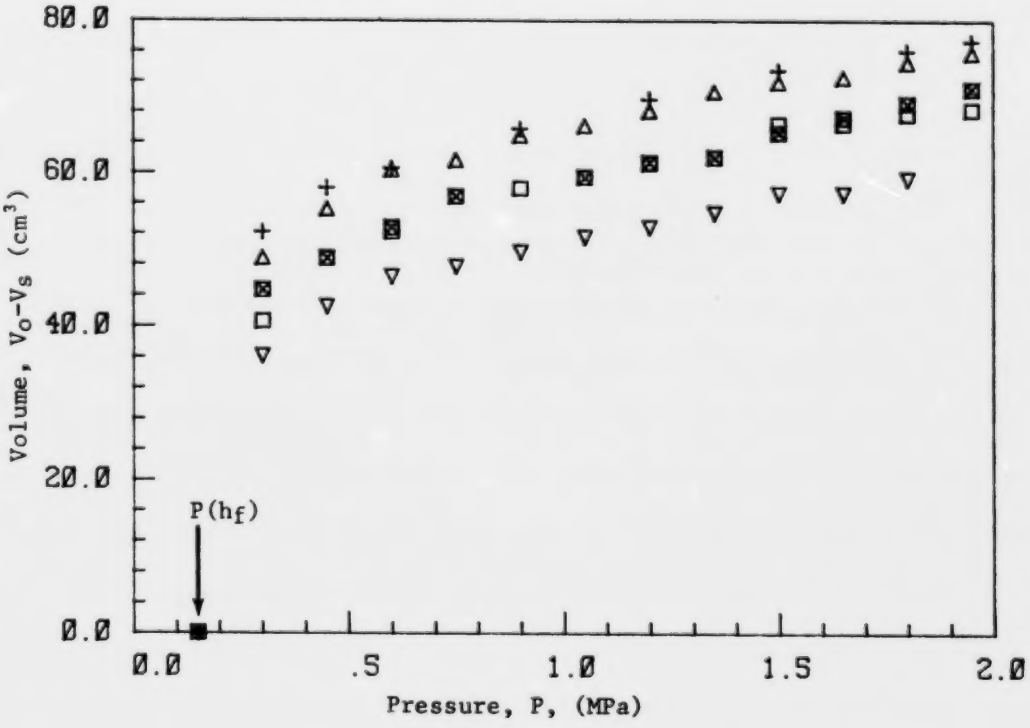

Fig. 3 - Lockerby Mine calibration test results.

Table 1 - Dilatometer calibration data

Test No.	C/Π (mm)	V_o (cm^3)	r (mm)	error, r_{ic} (%)	M_m (GPa/m^3)
1	116.2	888.2	64.8	+0.7	81.94
2	121.6	950.1	67.7	+5.3	90.68
3	114.0	1012.9	64.8	+0.7	85.90
4	113.3	1024.7	64.6	+0.5	97.68
5	113.0	1007.2	64.3	0.0	90.47
				Mean	89.33
					± 5.28

SITE PREPARATION

Depending upon the cement content of the backfill, special care may be required to drill a borehole suitable for dilatometer testing. Ideally, a 127 mm (5 inch) O.D. concrete drill should be used since core recovery and analysis for cement content is then possible, and probe access/recovery is easier. Whatever is used, however, the result should leave the borehole walls as intact as possible. A borehole TV camera ia a useful tool for the confirmation of a drilling method with respect to this requirement.

At both Lockerby and Selbaie 114 mm (4½ inch) boreholes were drilled. While this size was less than practicable at Lockerby in a stiff 12:1 CHF (the probe-hole clearance created some severe recovery problems), in the case of Selbaie's CRF it was found to be ideal. This was due to the drilling methods employed: at Lockerby a concrete drill, at Selbaie a shoe bit and water flushing followed by a tricone toothed bit. The latter method no doubt effected a larger hole due to wear in what was a weak and more difficult material (for a detailed description, see (2)).

MODULUS DETERMINATION; SELBAIE TESTS

SITE DESCRIPTION

At the completion of mining, blasthole stope 17-3-06 (see Mine Section, Fig. 4) was filled during February/March 1982 with a 2:1 rock:tailings, cemented rockfill. Cement content was 1.3% total volume. Later, during December, a footwall cross-cut on 170 m level made access with the backfill and exposed a surface measuring approximately 4 m x 4 m. Finally, in early March 1983, six holes, 114 mm diameter x 6 m long, were drilled according to the layout, Fig. 5, for dilatometer testing. Inspection of all available holes using a scanning TV borehole camera resulted in the elimination of horizontal holes 02 and 03 from the measuring program. The remaining showed good integrity with some local voids located for avoidance during probe positioning.

RESULTS

A total of four measurements were made, two in each of the holes 04 and 06. The remaining holes will be used in late 1983 following the removal of an adjacent pillar (stope 17-3-05). Field data and deformation modulus calculated using calibration data and Equation 4 are presented in Fig. 6 and Table 2. While the scatter in these data is quite reasonable for such a coarse weakly cemented rockfill, the influence of drilling upon borehole wall stiffness (i.e., the modulus measured by the dilatometer) was questioned. Photographs taken before and after test number 04-1, Fig. 7, indicated little change in appearance at a rock aggregate/matrix interface. This in turn suggested the absence of a local gross loosening of borehole wall material. Nevertheless, a test devised to eliminate all drilling effects was performed later in the laboratory. This entailed casting a 115 mm diameter hole using

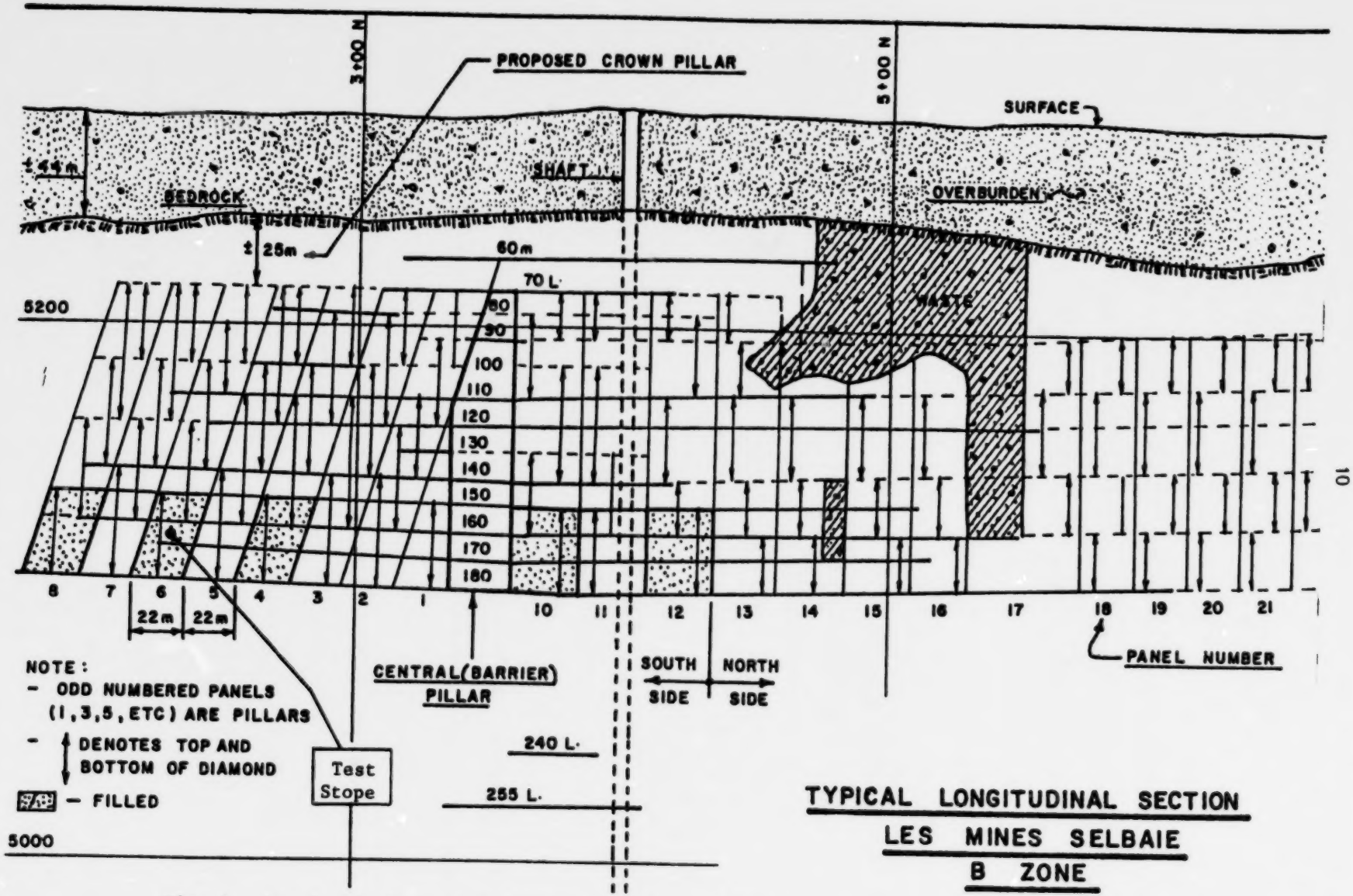

Fig. 4 - Longitudinal section showing location of filled stope 06 on south side of mine.

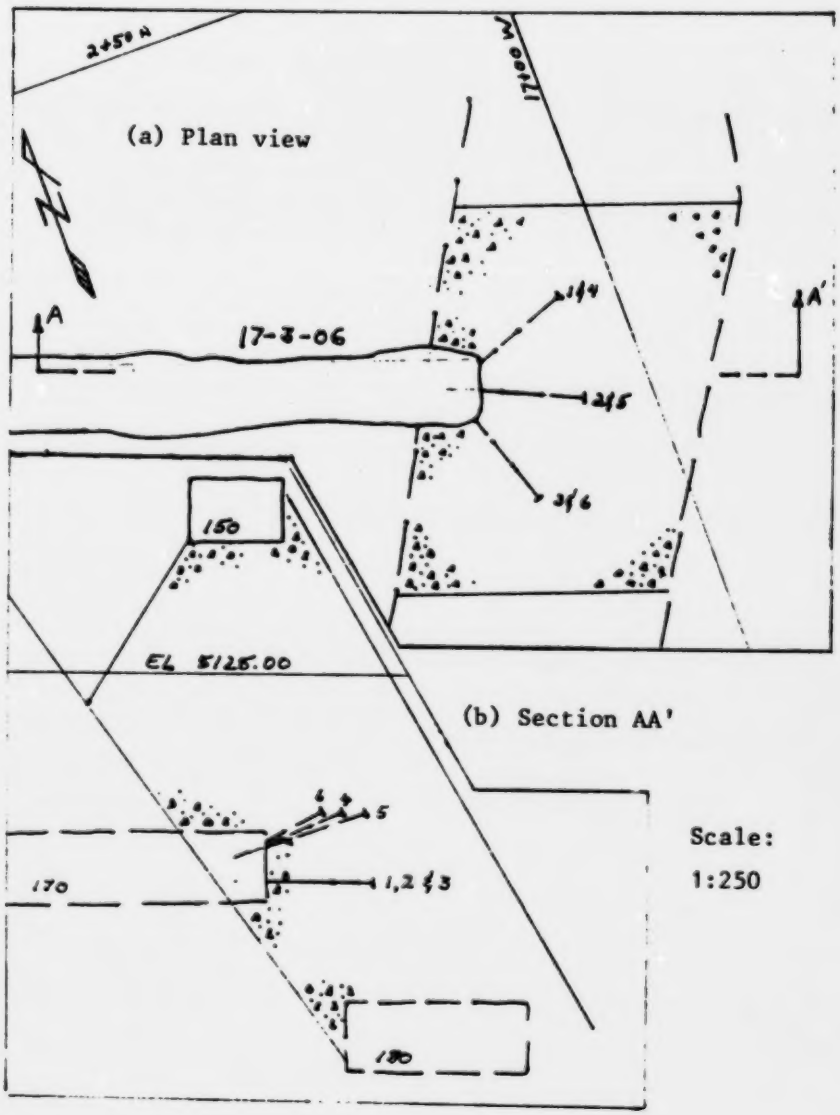

Fig. 5 - Plan and vertical section of stope 17-3-06 showing dilatometer borehole locations.

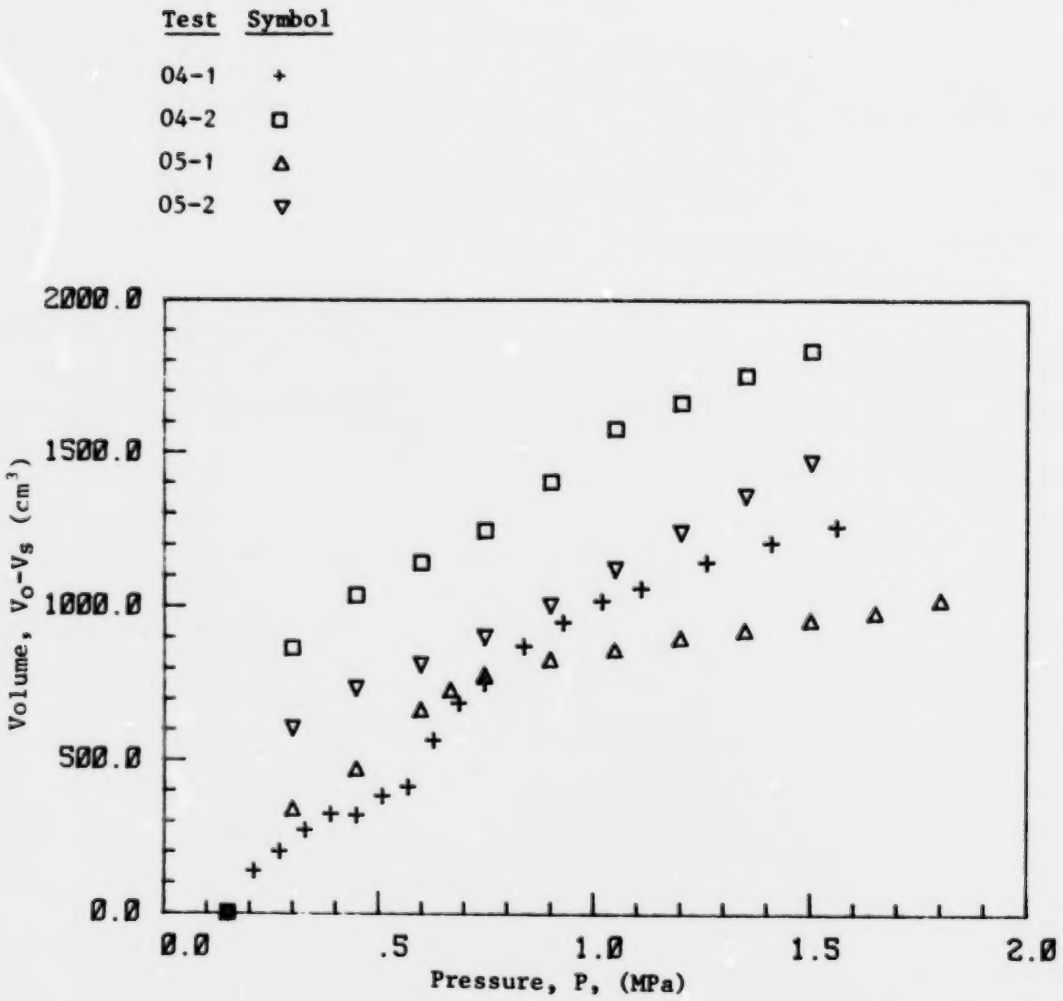

Fig. 6 - Dilatometer pressure-volume data, Selbaie Mine.

Table 2 - Dilatometer results, Selbaie Mine

Test No.	Depth (m)	V_o (cm^3)	r (mm)	Range (MPa)	Modulus, E_B (MPa)
04-1	1.8	737	122.4	0.20 - 2.00	8.6 - 27.0
04-2	3.5	1054	128.1	0.20 - 2.00	13.1 - 20.7
05-1	1.8	1056	133.0	0.20 - 2.00	11.1 - 66.9
05.2	3.6	1025	132.1	0.20 - 2.00	16.3
				Mean =	32.7
				at 2 MPa	±20.1

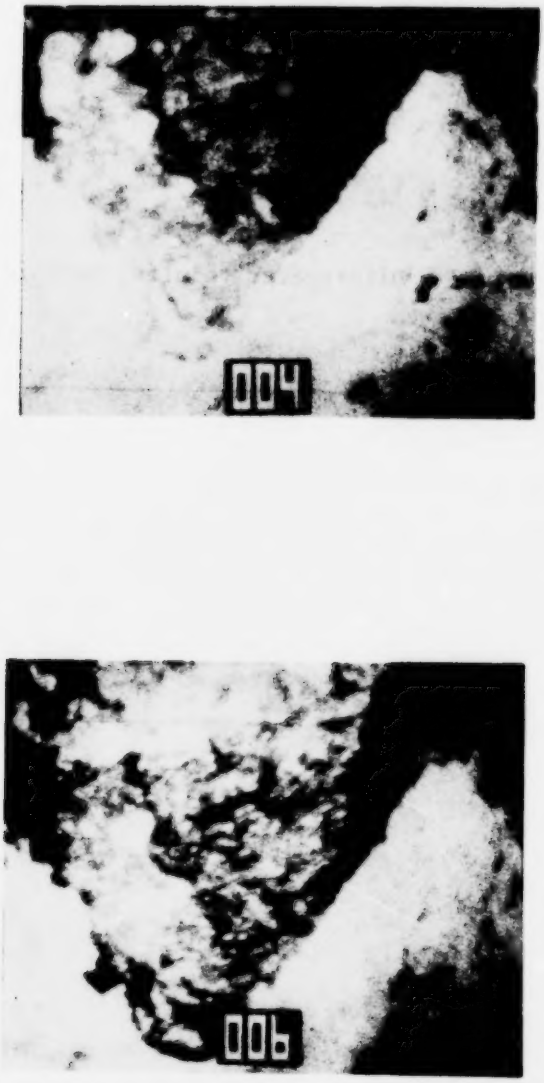

Fig. 7 - Scanning borehole TV picture of a selected rock particle/matrix interface: (A) before test; (B) after test. Scale: 3 cm:10 mm.

the same rockfill/cement proportions in a 45 gallon oil drum. After curing for 28 days at room temperature a dilatometer test was conducted. The result, which provided a deformation modulus of 106.2 MPa over the pressure range 0.20 to 2.00 MPa, may be considered an upper bound value.

MODULUS DETERMINATION; LOCKERBY TESTS

SITE DESCRIPTION

Prior to May 1983, complete access to 22-143 stope's cemented hydraulic fill (CHF) was afforded via the undercut and overcut levels of the adjacent 22-139 stope. The levels, approximately 38 m apart in elevation, permitted the entry and drilling of five 114 mm diameter boreholes into the CHF. These were drilled sub-horizontal and orientated along the orebody's strike, Fig. 8, using a thin walled concrete bit. Core recovery was good enough to provide cores for laboratory uniaxial compression and cement content tests.

Subsequent to May 19th, when a single measurement of E_B for each undisturbed hole was finalized, weekly measurements were taken at the completion of the blasting and mucking cycle in stope 22-139. The loss of access to all holes occurred by July 8th at which time seven sets of dilatometer readings had been taken.

Concurrent with the above dilatometer tests, Falconbridge undertook on-site blast vibration monitoring by installing a geophone in the 143 stope backfill near the rockfill interface. In addition, three extensometers were installed to monitor possible movements in the hangingwall (or northwall), backfill and adjacent rock pillar (22-134 stope).

RESULTS

For each dilatometer measurement the pressure-volume data was plotted (see Appendix) and the reduction procedures outlined in Section 2 were applied.

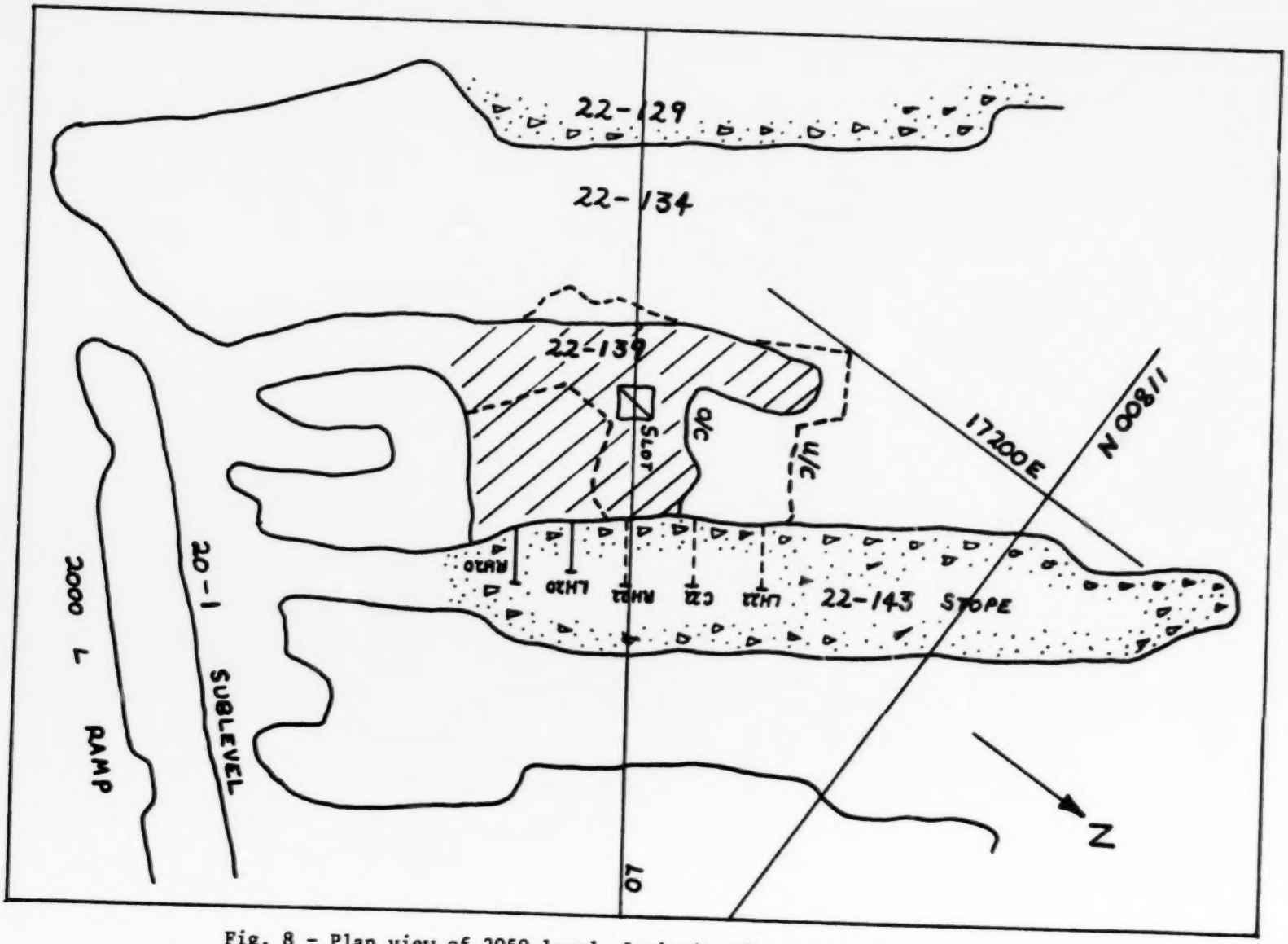

Fig. 8 - Plan view of 2050 level, Lockerby Mine, showing dilatometer borehole locations in 22-143 stope. Scale: 1 in = 40 ft.

Except for the case of a measurement close to the hole collar (see Fig. A-6) or erroneous data due to an air leak (see Fig. A-2), a strong linear dependency of volume upon pressure was observed over the pressure range 0.6 to 2.0 MPa. Complete results are presented in Table 3 and for an average depth the time-dependent deformation modulus for each hole is plotted in Fig. 9.

DISCUSSION

Examples of comparisons between in situ dilatometer and uniaxial/triaxial laboratory determinations of deformation modulus exist in the literature. At issue is the degree of disturbance undergone by the laboratory samples and how this may invalidate results. Thus for a water-sensitive black shale (uniaxial compressive strength $\cong$ 1.5 MPa) dilatometer tests gave values five to thirteen times the laboratory undrained modulus (5). In general, however, the specimens selected for laboratory tests will necessarily be of better average quality than the overall material and, as a result, the reverse will be true (6).

For the two backfills examined in this report, laboratory values from uniaxial compression tests are available. The Selbaie data, from moulded specimens (measuring 300 mm diameter x 600 mm long(2)), provide values approximately 30% in excess of dilatometer values reported above. This seems quite reasonable considering moulded specimens provide for optimum mixing/curing conditions. In contrast, cores from the diamond-drilled Lockerby dilatometer boreholes (measuring 114 mm diameter x 250 mm long after cutting) were tested from plastic bags sealed on site. The results, Table 4, may be compared hole by hole and even location (i.e., depth) by location. Thus, hole C22 for depths between 2.3 and 4.7 m has a modulus range for which both methods show agreement. Furthermore, the wide-ranging dilatometer modulus values can be accounted for

Table 3 - Dilatometer results, Lockerby Mine

Test Hole-Date	Depth (m)	V_o (cm^3)	r (mm)	Modulus E_B (GPa)
LH20-1705	1.3	503	121.6	0.16
RH20-1805	2.8	922	125.9	0.09
C22-1805	2.8	86	115.0	0.85
RH22-1905	5.5	1061	127.2	0.29
LH22-1905	5.5	1156	132.1	0.35
LH20-2505	2.3	507	121.4	0.13
RH20-2505	3.4	121	117.8	0.20
C22-2505	4.1	136	116.8	0.61
RH22-2605	4.9	1201	133.1	0.26
LH22-2605	4.9	573	126.9	0.63
LH20-0106	2.1	156	117.4	0.20
RH20-0106	2.5	163	119.1	0.23
C22-0206	3.5	50	115.7	1.20
RH22-0206	5.2	301	120.4	0.52
LH22-0206	4.9	93	116.1	0.64
LH20-0806	1.5	386	120.5	0.22
RH20-0806	3.1	186	117.6	0.28
C22-1006	4.3	140	115.9	0.63
RH22-1006	5.2	384	118.9	0.74
LH22-1006	4.9	189	116.4	0.67
LH20-1606	2.4	460	121.9	0.20
RH20-1606	3.1	193	116.7	0.30
C22-1706	3.7	88	116.6	1.05
RH22-1706	5.0	719	125.2	0.64
LH22-1706	4.9	142	116.3	0.75
LH20-2306	2.3	343	121.3	0.24
RH20-2306	2.8	226	117.9	0.30
LH20-0807	2.4	317	119.9	0.25
RH20-0807	3.1	114	117.0	0.32

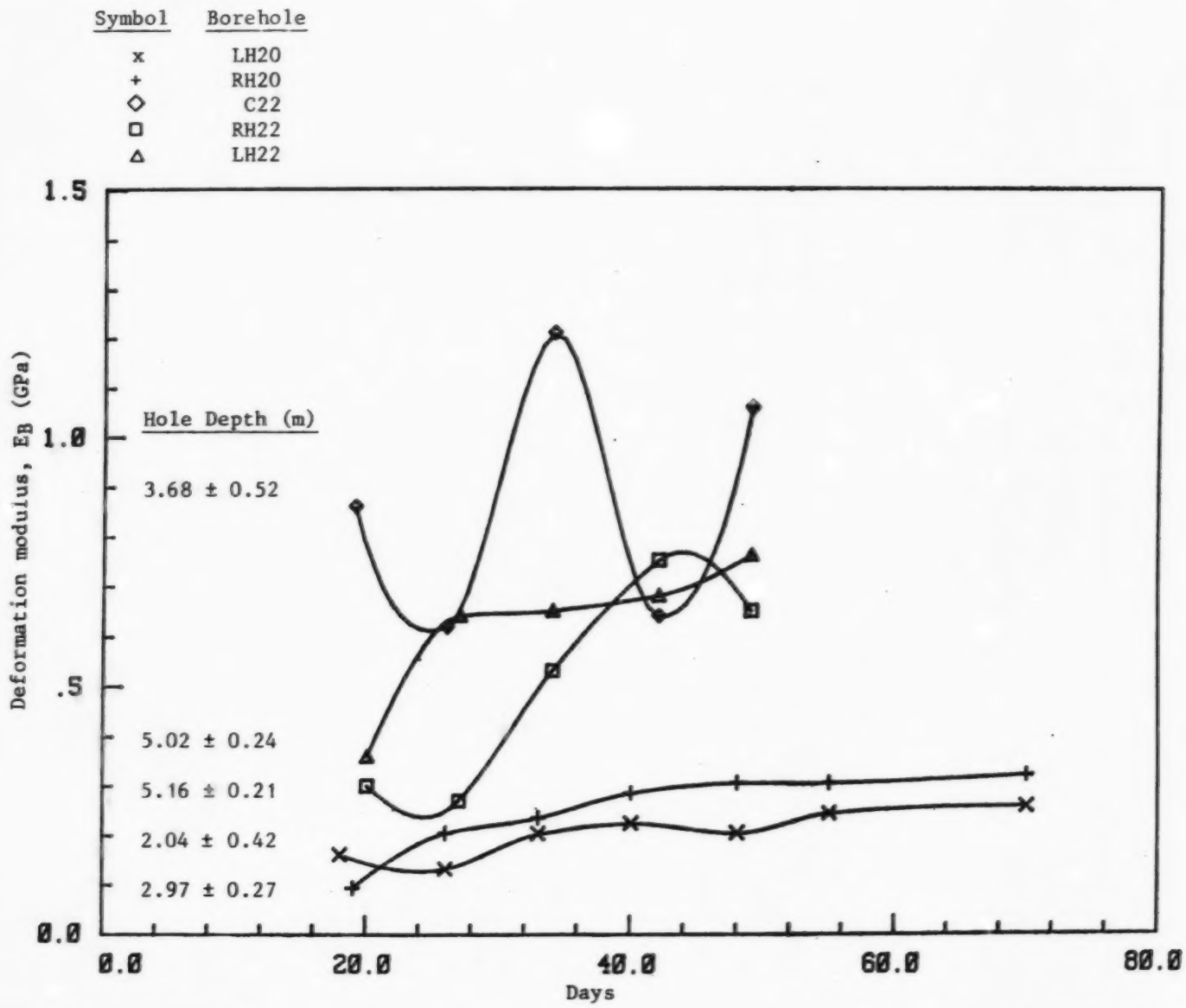

Fig. 9 - Deformation modulus variation with time (datum at commencement of drilling boreholes). Depth location of each hole measurement is given as mean and standard deviation.

Table 4 - Uniaxial compression test results on Lockerby CHF drill core (E_{50s} = secant modulus @ 50% strength)

Test Hole - Depth(m)	Compressive Strength (MPa)	E_{50s} (GPa)	Moisture (wt. %)	Dry Density (kg/m^3)
RH20 - 5.2	1.39	0.56	16.9	1693
C22 - 1.4	3.13	1.48	22.5	1481
C22 - 2.3	2.57	1.17	17.0	1742
C22 - 3.7	4.06	1.57	22.2	1474
C22 - 4.7	1.61	0.62	30.4	1174
LH22 - 1.3	3.81	1.91	-	-
LH22 - 1.8	2.96	0.74	-	-
LH22 - 2.2	1.96	0.73	20.0	1703
LH22 - 3.9	3.75	1.60	23.7	1364
LH22 - 5.5	1.10	0.69	-	-
RH22 - 0.9	1.74	0.32	42.9	830
RH22 - 1.5	2.48	0.56	26.8	1378

on the basis of the variable density seen in the core specimens, Table 4. The results do in fact, for this well-cemented CHF, show good general agreement. A justification for the use of the dilatometer in this case is that backfill stiffness (and thereby its potential to fail under free standing conditions) can be monitored at later dates without resort to additional core drilling. Such follow-up work is planned at Lockerby in the overcut level after 22-139 stope is filled. This, among other things, makes the dilatometer a useful and cost effective tool for the investigation of in situ backfill properties.

Concerning the technical performance of the dilatometer, it was found that the guard cell (see Fig. 1) was prone to air leaks at elevated pressures. This troublesome effect will be eliminated by the incorporation of a positive means of regulating air to the cell, rather than the indirect method used presently (4). While this may raise the maximum working pressure of the dilatometer to values in excess of 2 MPa, its capability to achieve a 'limit', failure or non-linear dilatancy condition in backfill will still be limited. In this case performing measurements near to the hole collar (~1 m) where confinement is least may be the only practicable solution with the present probe construction (cf RH20 measurements at 1.8 and 2.8 m depth, Fig. A-6).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable on-site assistance of P. Bonneville and P. St. George of Les Mines Selbaie, Quebec, and S. Bharti and D. Dileo of Falconbridge Nickel Mines Ltd., Ontario.

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APPENDIX

Lockerby Mine dilatometer test results,

22-143 stope, May 17th - July 8th, 1983.

Symbol	Borehole
X	LH20
+	RH20
◇	C22
□	RH22
△	LH22

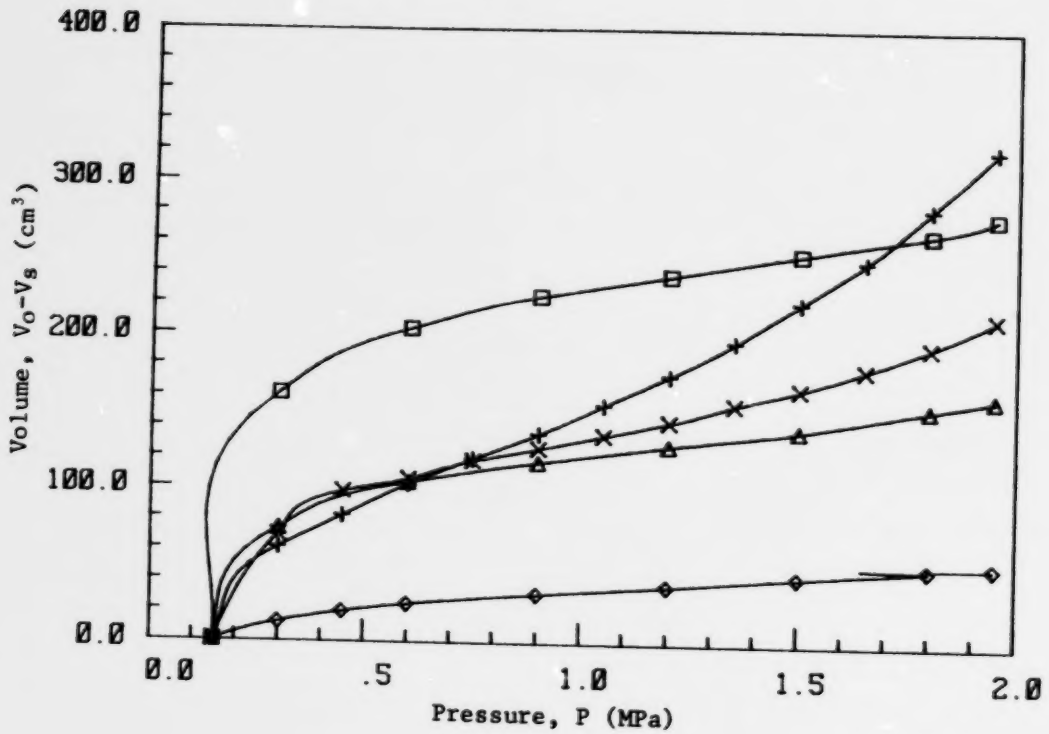

Fig. A-1 - Dilatometer results taken during May 17th - 19th, 1983, 22-143 stope, Lockerby Mine.

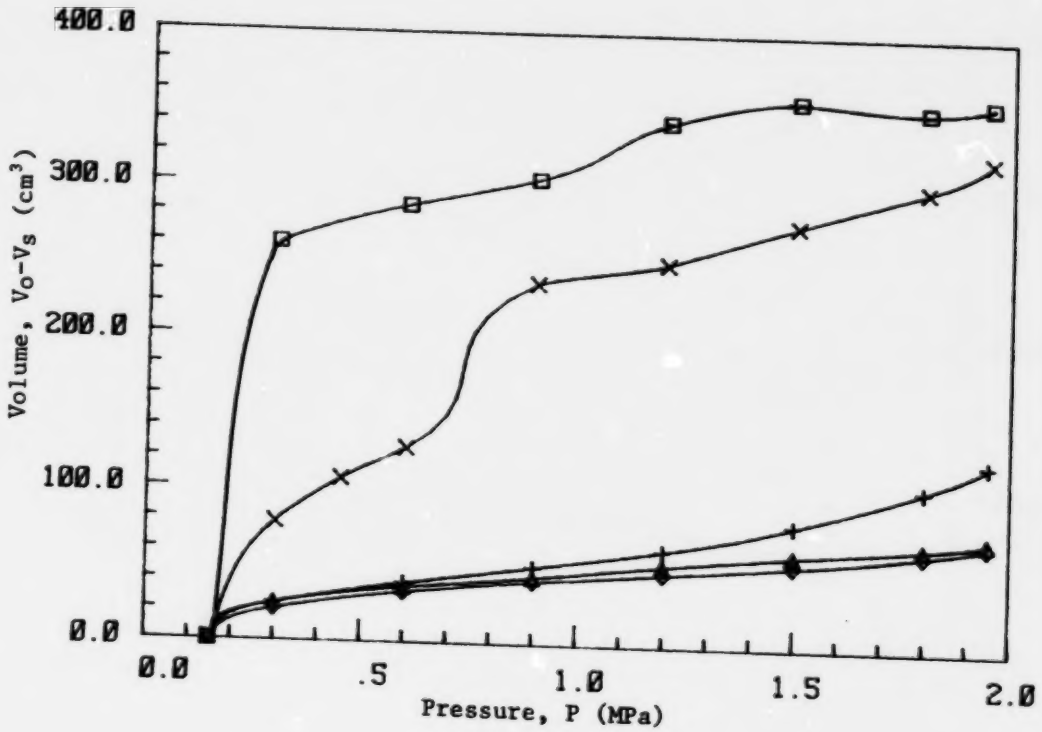

Fig. A-2 - Dilatometer results taken during May 25th - 26th, 1983, 22-143 stope, Lockerby Mine. Note air leak was observed during LH2O measurement.

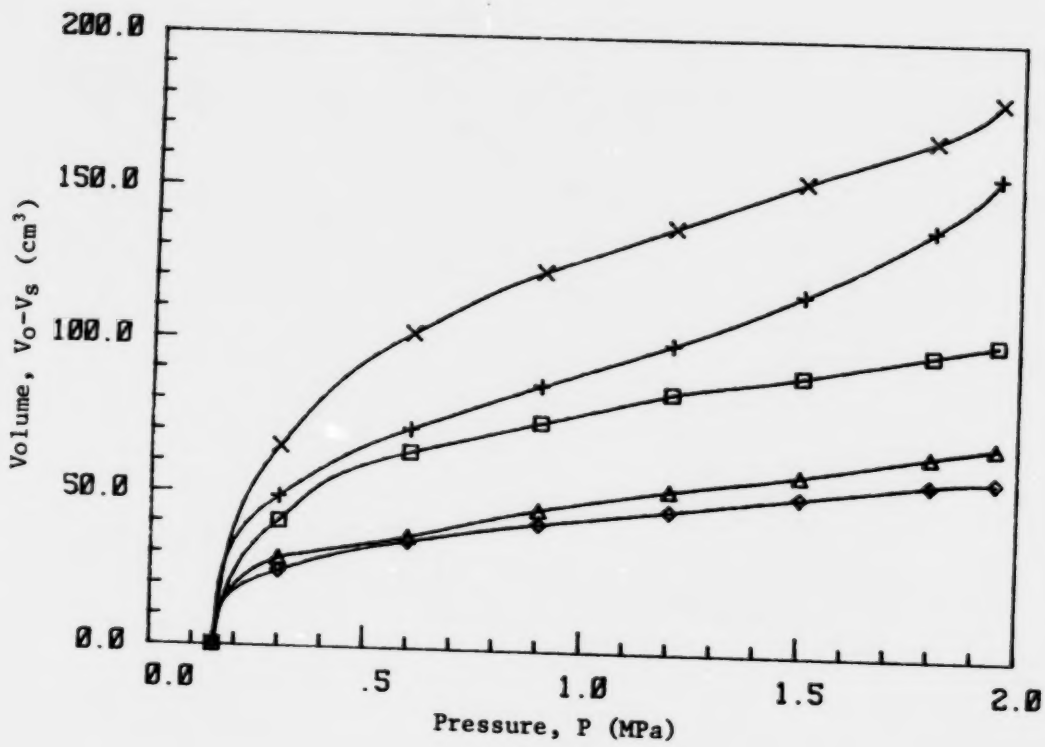

Fig. A-3 - Dilatometer results taken during June 1st - 2nd, 1983, 22-143 stope, Lockerby Mine.

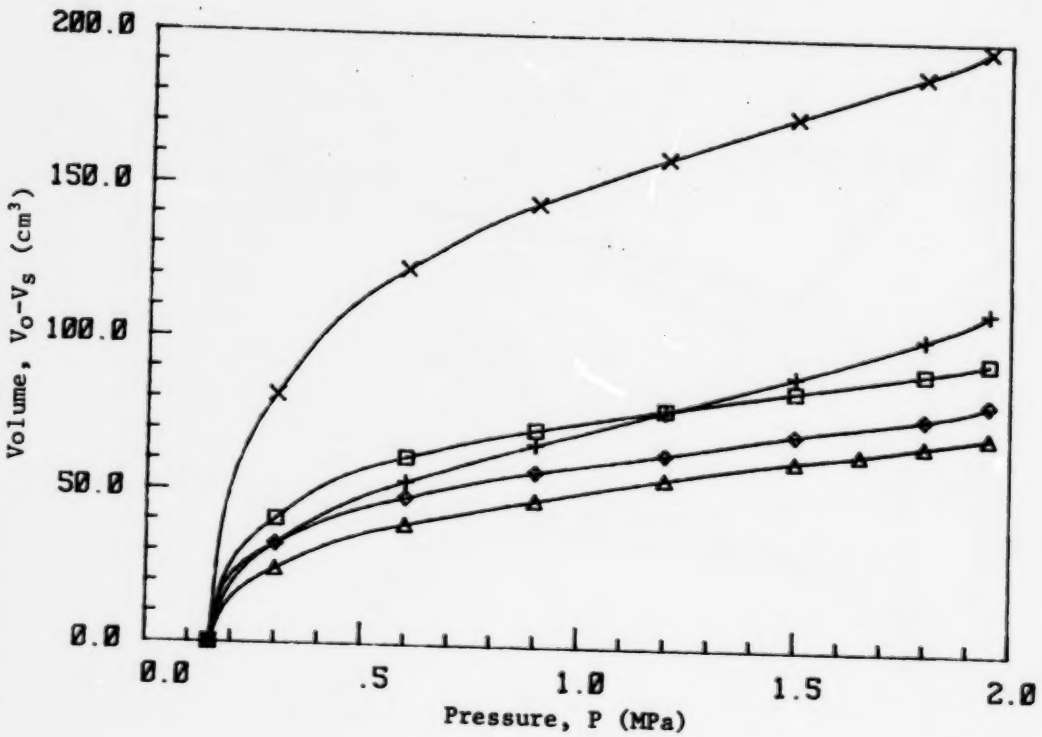

Fig. A-4 - Dilatometer results taken during June 8th - 10th, 1983, 22-143 stope, Lockerby Mine.

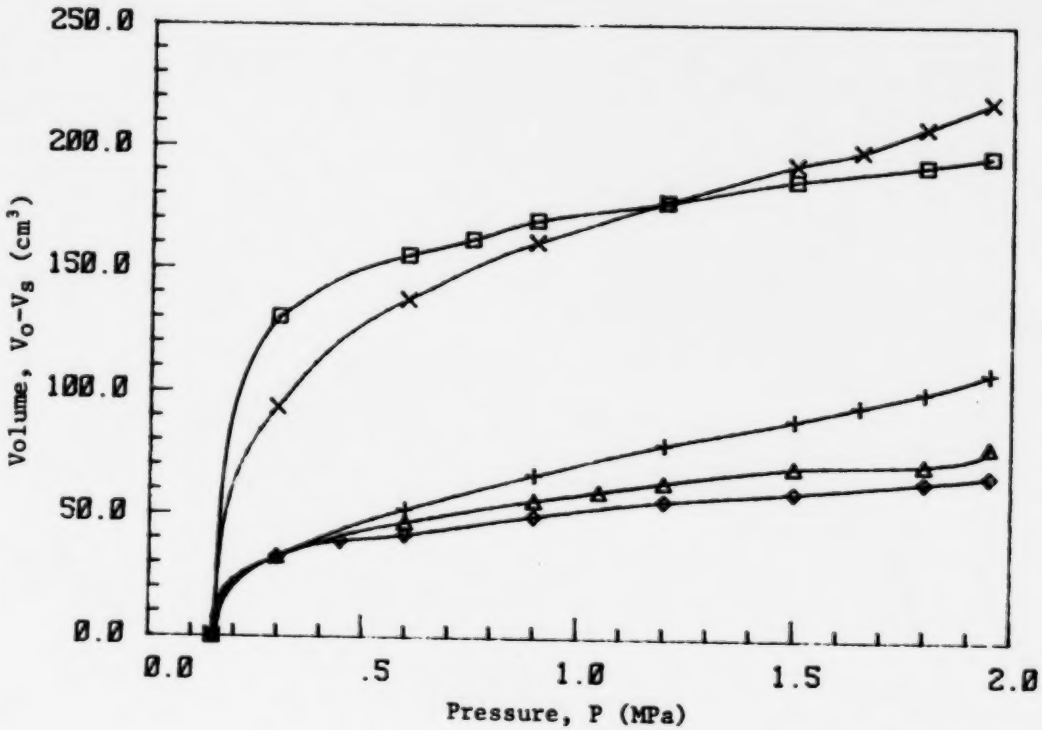

Fig. A-5 - Dilatometer results taken during June 16th-17th, 1983, 22-143 stope, Lockerby Mine.

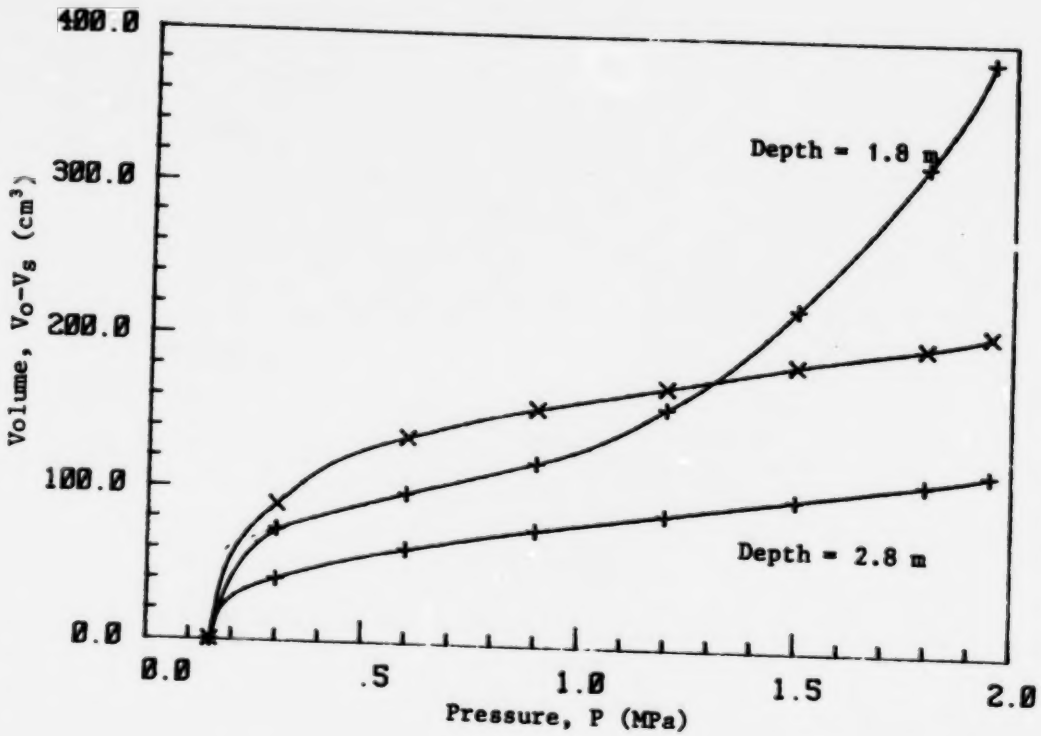

Fig. A-6 - Dilatometer results taken on June 23rd, 1983, 22-143 stope, Lockerby Mine. Note: two measurements taken in RH2O at different depths.

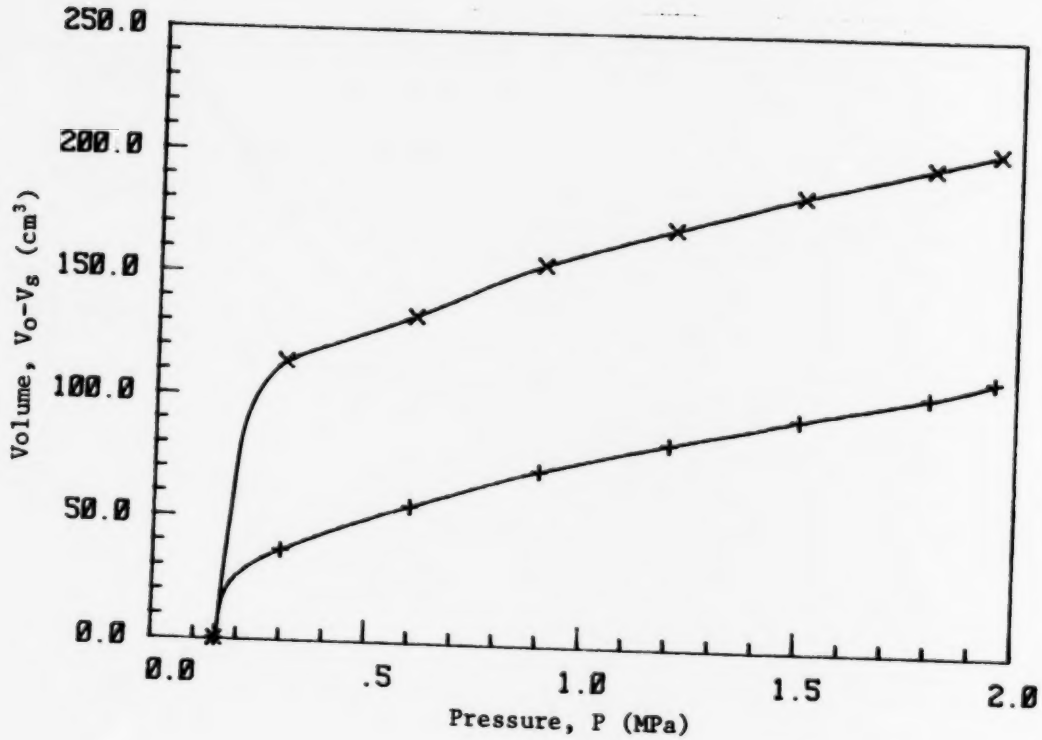

Fig. A-7 - Dilatometer results taken on July 8th, 1983, 22-143 stope, Lockerby Mine.